WATERSHED SCALE ASSESSMENT OF THE IMPACT OF FORESTED RIPARIAN ZONES ON STREAM WATER QUALITY

J.A. Webber, K.W.J. Williard, M.R. Whiles, M.L. Stone, J.J. Zaczek, and D.K. Davie[1]

ABSTRACT.—Federal and state land management agencies have been promoting forest and grass riparian zones to combat non-point source nutrient and sediment pollution of our nations' waters. The majority of research examining the effectiveness of riparian buffers at reducing nutrient and sediment inputs to streams has been conducted at the field scale. This study took a broader watershed approach in assessing the stream water quality benefits of forested riparian buffer zones. Stream nitrate, orthophosphate, and ammonium concentrations were compared in 11 agriculturally impacted watersheds with varying percentages of riparian forest area. The study catchments are located in the Sugar Creek watershed in southern Illinois and contain similar soil types and land uses (predominately row crop agriculture). The Geographic Information System software, ArcView 3.2 (ESRI), was used to delineate the Percent Forested Area in the Riparian Buffer Zone (PFARBZ), within 15 m of the stream across the total length of the 1st and 2nd order streams within each catchment. Stream water samples were collected at baseflow over a 9-month period for nutrient analysis. Preliminary results suggest that watersheds with greater PFARBZ have lower dissolved stream PO_4^{-3}-P concentrations. However, no significant relationship was found between PFARBZ and dissolved stream NH_4^+-N and NO_3^--N concentrations.

Throughout the Midwestern United States, agriculture has been and continues to be the predominant land use. Agriculture is considered a major contributor to stream degradation in the United States, having adverse effects on in-stream habitats and water quality (USEPA 1994). Nutrient loading and sediment deposition have been identified as the water quality problems of greatest concern (Chester and Schierow 1985).

Over the past few decades, studies have been conducted to examine the amount of nutrients carried in runoff, factors that affect nutrient runoff, and how nutrient export can be minimized (Lowrance and others 1983, Peterjohn and Correll 1984, Pinay and Decamps 1988, Muscutt and others 1993, Edwards 1996). One tool that has become widely accepted to reduce excess nutrient and sediment export is vegetated riparian buffer zones.

The primary determinants of the volume and kinetics of external inputs into a riparian zone are derived from the watershed's land use, size, and gradient. Recent literature suggests that riparian buffer zones can facilitate water quality improvements in different ways depending on how water passes through the buffer zone (Muscutt and others 1993, Correll 1996, Herron and Hairsine 1998). A forested riparian zone can effectively filter lateral overland flow when it enters the buffer strip as sheet flow draining from a small field with a minimal slope of 5 percent or less (Peterjohn and Correll 1984). In addition, several studies have shown that riparian

---

[1] Graduate Assistant (JAW), Assistant Professor (KWJW), and Assistant Professor (JJZ), Department of Forestry; Assistant Professor (MRW) and Graduate Assistant (MLS), Department of Zoology; and Researcher III (DKD), Morris Library, Southern Illinois University, Carbondale IL 62901-4411. KWJW is corresponding author: to contact, call (618) 453-7478 or e-mail at williard@siu.edu.

Citation for proceedings: Van Sambeek, J.W.; Dawson, J.O.; Ponder, F., Jr.; Loewenstein, E.F.; Fralish, J.S., eds. 2003. Proceedings, 13th Central Hardwood Forest conference; 2002 April 1-3; Urbana, IL. Gen. Tech. Rep. NC-234. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 565 p. [Peer-reviewed paper from oral presentation].

zones can decrease the nutrient levels of groundwater entering streams (Jacobs and Gilliam 1985, Cooper 1990, Haycock and Pinay 1993, Jordan and others 1993).

The majority of research aimed at quantifying the water quality benefits of forested riparian buffer zones has been conducted at the field scale (Groffman and others 1991, Haycock and Pinay 1993, Addy and others 1999). Herron and Hairsine (1998) suggested that land management initiatives need to be directed at the catchment scale if riparian buffers of realistic widths are to be effective. This study examined the effectiveness of forested riparian zones at attenuating agricultural nutrient inputs to streams at the watershed scale. We hypothesized that nutrient concentrations would decrease as percent forested area within riparian buffer zones (PFARBZ) increased.

METHODS

Eleven headwater watersheds with varying percentages of riparian forest cover were located within the Illinois Department of Natural Resources (IDNR) Sugar Creek Pilot Watershed, Clinton, Bond, and Madison Counties, Illinois, in the fall of 2000 (fig. 1). The 11 watersheds were selected using 1998 Digital Ortho-photo Quadrangles (DOQ's; 1 m resolution). We found the predominant land-use on all of the watersheds to be row crop agriculture, and assumed

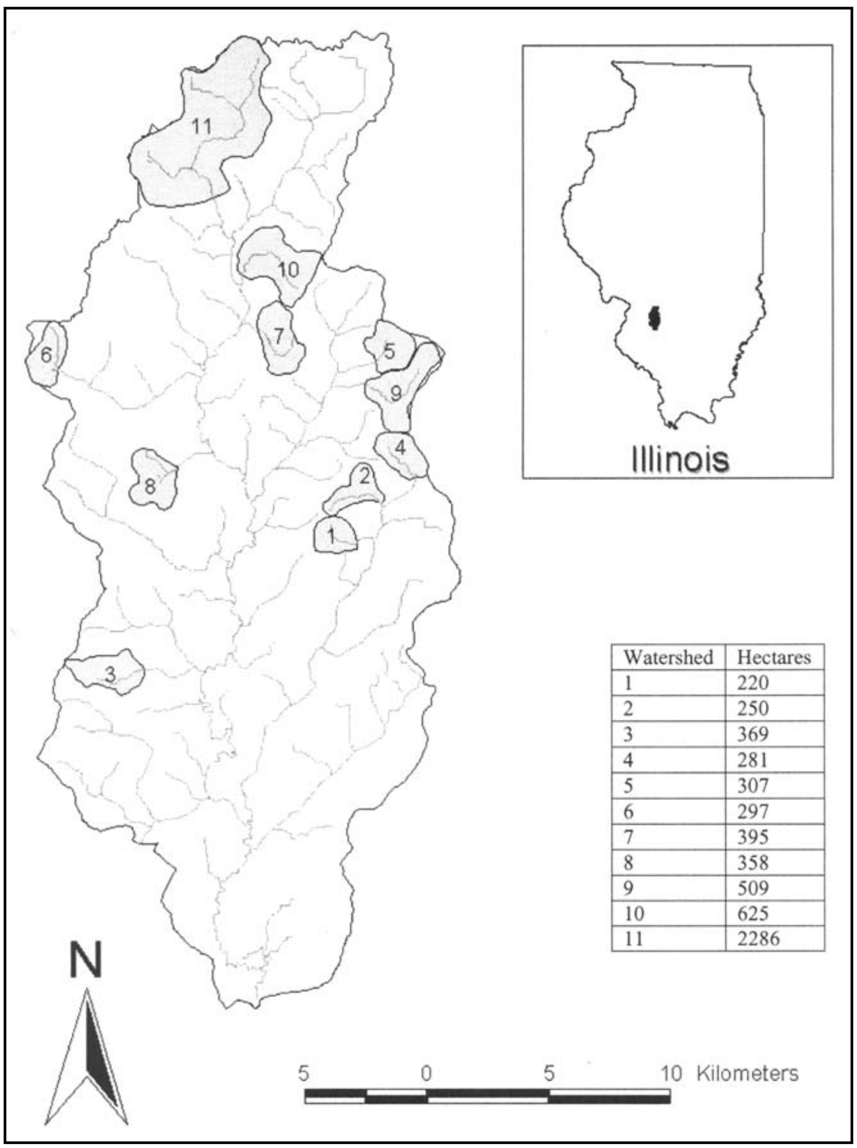

Figure 1.—*Location of study watersheds within the Sugar Creek drainage, Illinois.*

that nitrogen and phosphorus fertilizer application rates were similar across the study catchements.

County stream image data files provided by the Illinois Natural Resource Geospatial Data Clearinghouse (INRGDC) were used to identify the stream channels (INRGDC 2000). All visible drainage networks, 1st and 2nd order streams, within the watershed were also digitized and added to the total stream length. A 15-m buffer zone was created on each side of a stream, and the total area within the 15-m buffer zones was derived. The presence of forested area within the 15-m riparian zone was also digitized from the DOQ's using ArcView 3.2 (ESRI). The total area of forest within the 15-m buffer zone was divided by the total area of the 15-m buffer zone to estimate PFARBZ. Riparian forest species composition was primarily early successional species.

All but one of the study watersheds was less than 700 ha in area (fig. 1). The watersheds contained a variety of soil types and complexes within the riparian areas including: Wakeland silt loam, Blackoar silt loam, Blair silty clay loam, Darmstadt-oconee complex, Cowden-Piasa complex, Virden silt loam, Muren silt loam, Hickory clay loam, Oconee silt loam, Wakeland silt loam, Fayet silt loam, Virden-Piasa silty loam, and Rozetta silty clay loam.

Stream water grab samples were collected monthly (May-December 2001) during baseflow conditions. Due to the intermittent nature of some of the study streams in September and October, 81 of the possible 88 samples (11 streams * 8 sampling dates) were taken. The samples were collected at a medium depth in the middle of the stream cross-section. The stream sampling point was located at the defined mouth of each stream (fig. 1). Samples were transported on ice to the Forestry Laboratory of Watershed research (FLOW) at Southern Illinois University, Carbondale, for analysis.

Stream samples were analyzed for pH, conductivity, and dissolved orthophosphate (PO_4^{-3}-P), nitrate (NO_3^--N), and ammonium (NH_4^+-N) concentrations. Dissolved orthophosphate (standard method 8178) and dissolved ammonium (standard method 8048) were measured using a Hach 4000D spectrophotometer. Dissolved nitrate was analyzed on a Dionex Ion Chromatograph Series 4000i. Conductivity and pH were measured using a Fisher Scientific AR 20 pH/conductivity meter. Results were compiled and averaged by site for the eight collection dates. Regression analysis was performed with each of the water quality parameter means and PFARBZ using the JMP in 4 Academic software package from the SAS Institute, Cary, NC. Significant relationships were tested at the α=0.05 level.

RESULTS

The ranges of PO_4^{-3}-P, NH_4^+-N, and NO_3^--N concentrations (mg L^{-1}) across the 11 watersheds were 0.000 to 11.709, 0.010 to 12.860, and 0.042 to 4.440, respectively. PFARBZ exhibited a significant (p=0.009) negative relationship with, and explained 50 percent of the variation in dissolved PO_4^{-3}-P concentrations across the 11 study watersheds (fig. 2). No significant relationships were found between PFARBZ and dissolved NH_4^+-N or NO_3^--N concentrations across the study watersheds (figs. 3 and 4). In addition, stream pH and conductivity were not significantly related to PFARBZ.

DISCUSSION

Numerous investigations have reported that naturally established riparian buffers reduce the impact of agriculturally derived nonpoint source pollutants in surface waters (Lowrance and others 1984, Peterjohn and Correll 1984, Jacobs and Gilliam 1985, Jordan and others 1993, Synder and others 1998). Several studies have shown that riparian forests can decrease phosphorus concentrations in overland flow from adjacent row crop fields (Dillaha and others 1989, Gilliam 1994, Daniels and Gilliam 1996, Lyons and others 1998). Results from this study suggest that percent forested buffer area at the watershed scale is an adequate predictor of dissolved phosphate concentrations. These findings support those of Jones and others (2001), who found that the percentage of forested stream miles within a watershed explained 63 percent of the variation in dissolved stream phosphorus levels in the Mid-Atlantic region of the United States.

Forested riparian zones have also been shown to reduce dissolved nitrate concentrations in groundwater entering the riparian zone from adjacent row crop fields (Lowrance and others 1984, Peterjohn and Correll 1984, Jacobs and Gilliam 1985, Cooper 1990, Schipper and others 1991, Osborne and Kovacic 1993, Synder and others 1998). However, our study did not show a significant relationship between PFARBZ and dissolved stream nitrate concentrations (fig. 4). James and others (1990) also found that

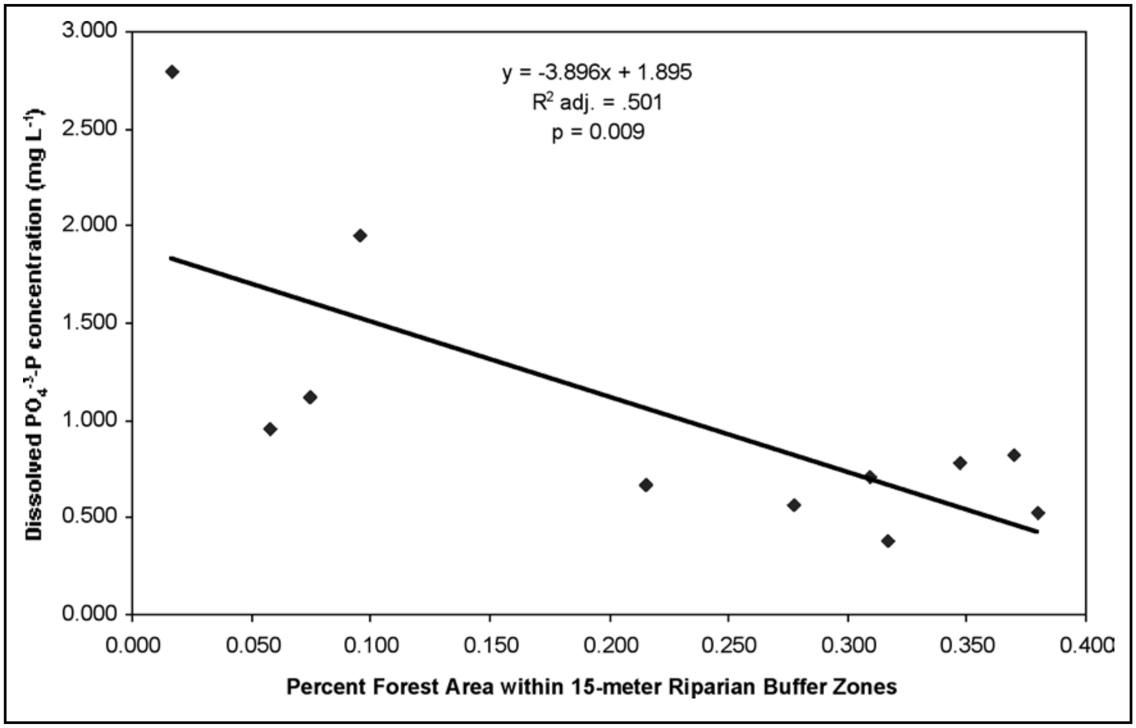

Figure 2.—*Dissolved PO_4^{-3}-P concentration versus percent forest area within 15-m riparian buffer zones.*

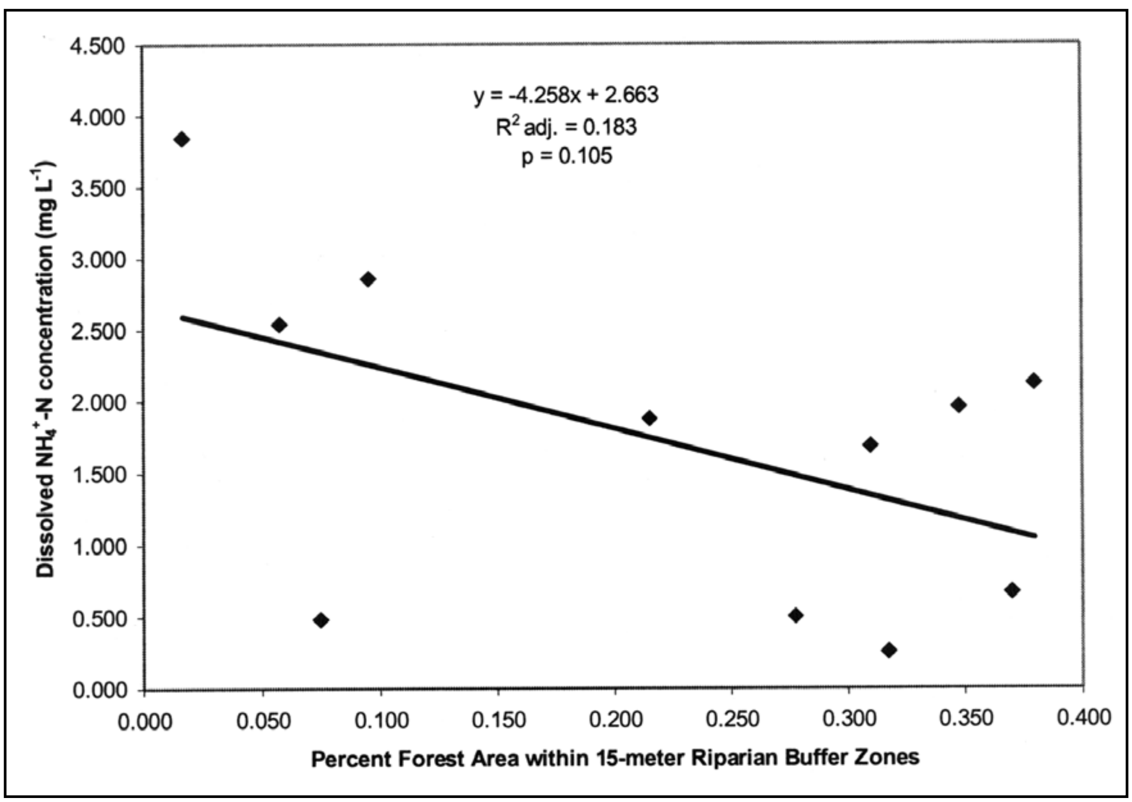

Figure 3.—*Dissolved NH_4^+-N concentration versus percent forest area within 15-m riparian buffer zones.*

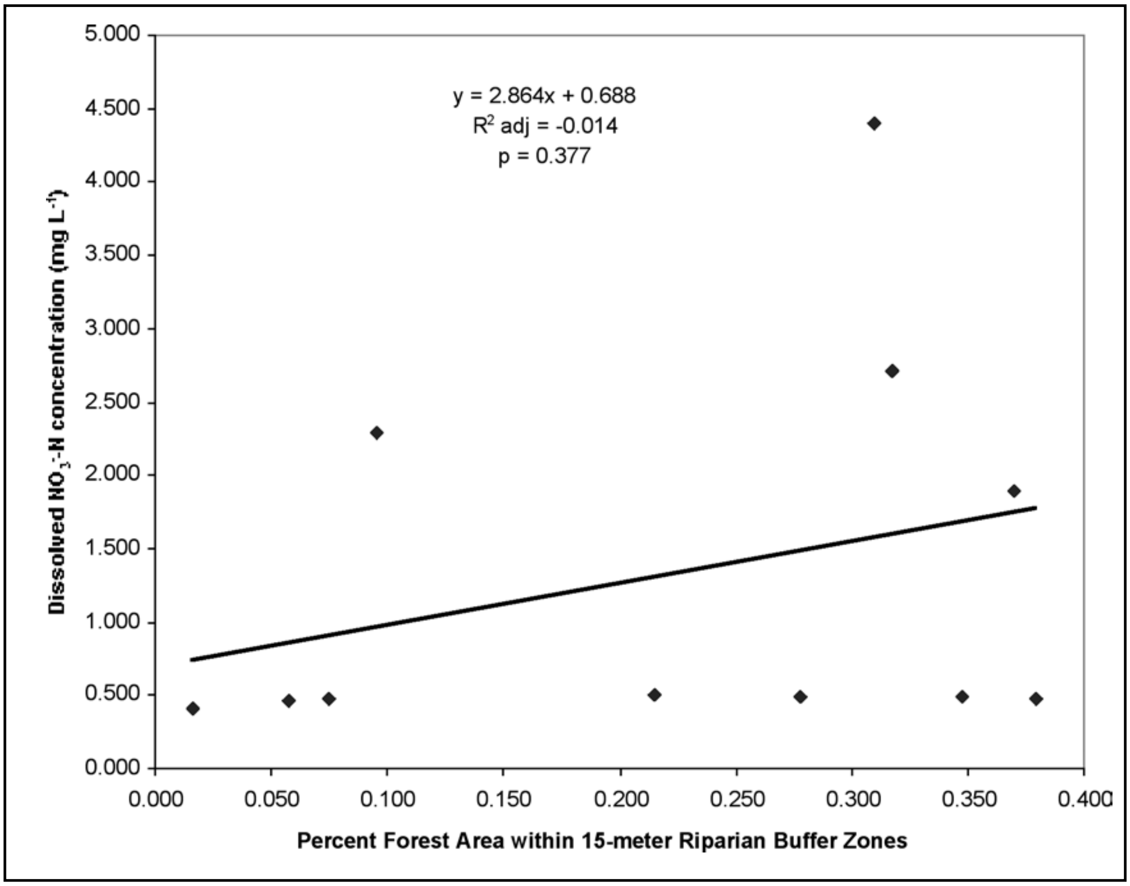

Figure 4.—*Dissolved NO_3-N concentration versus percent forest area within 15-m riparian buffer zones.*

riparian forests did not reduce dissolved nitrate concentrations in groundwater.

Prior studies have shown that forested riparian zones can reduce ammonium concentrations entering as surface flow from adjacent agricultural lands (Peterjohn and Correll 1984, Daniels and Gillaim 1996). Our results show that dissolved ammonium concentrations were not significantly correlated with PFARBZ (fig. 3), but showed a non-significant trend that would become significant by eliminating one point, a site with low PFARBZ and low ammonium concentration. Aside from this site, ammonium concentrations decreased with increasing PFARBZ.

A potential reason for the lack of stronger relationships between PFARBZ and stream dissolved nitrogen species (NO_3^--N and NH_4^+-N) is that some or all of our study watersheds could be nitrogen saturated. The theory of nitrogen saturation was developed in the forestry literature to explain the existence of increased dissolved nitrogen export from forested watersheds within the past 2 decades (Agren and Bosatta 1988, Aber and others 1989, Van Miegroet and others 1992). Aber and others (1989, 1998) described nitrogen saturation as a series of stages where the capacity of an ecosystem's soil, microbes, and vegetation to retain nitrogen is gradually depleted due to chronic nitrogen inputs (atmospheric deposition). This may be occurring on our agricultural study watersheds due to nitrogen fertilizer applications, which are substantially higher than atmospheric deposition levels.

The observed non-relationship between PFARBZ and dissolved stream nitrogen concentrations could also be due to significant variability in riparian soil and in-stream denitrification rates among the 11 study watersheds. Several studies have shown riparian soil and in-stream denitrification rates to be highly variable within a watershed and among adjacent watersheds (Hill and Sanmugadas 1985, Cook and White 1987, Hill 1988).

CONCLUSIONS

Our study indicates that PFARBZ can be used to assess the effectiveness of forested riparian buffer zones at attenuating some nutrients at the watershed scale. PFARBZ exhibited a significant negative relationship with dissolved PO_4^{-3}-P concentrations, but did not show a significant relationship with dissolved NH_4^+-N or NO_3^--N concentrations, although there was a trend of lower ammonium in streams with higher PFARBZ. This lack of a relationship with dissolved stream nitrogen concentrations could be an indication that riparian buffer zones are nitrogen saturated or it may be due to differences in soil and in-stream denitrification rates in the study watersheds. Increasing the number of 1st and 2nd order streams sampled may prove to strengthen presented relationships. Future watershed scale analyses of the effectiveness of riparian zones could be expanded to include watersheds with riparian zones of differing species composition and ages.

ACNOWLEDGMENTS

The Illinois Council on Food and Agricultural Research (C-FAR) Water Quality Strategic Research Initiative (6-23416), the Southern Illinois University Carbondale Office of Research and Development Administration (2-11517), the College of Agricultural Sciences, College of Science, Department of Forestry, and Department of Zoology at Southern Illinois University Carbondale provided funding for this project. The authors thank Jon O'Brien, Jon Schoonover, Steve Fillmore, Chad Yocum, David Colon, Adam Hershfelt, and Chris Blattel for help with field data collection and laboratory analysis.

LITERATURE CITED

Aber, J.D.; Nadelhoffer, K.J.; Steudler, P.; Melillo, J.M. 1989. Nitrogen saturation in northern forest ecosystems. BioScience. 39: 378-387.

Aber, J.D.; McDowell, W.; Nadelhoffer, K.; Magill, A.; Berntson, G.; Kamakea, M.; McNulty, S.; Currie, W.; Rustad, L.; Fernandez, I. 1998. Nitrogen saturation in temperate forest ecosystems: hypotheses revisited. BioScience. 48(11): 921-934.

Addy, K.L.; Gold, A.J.; Groffman P.M.; Jacinthe, P.A. 1999. Ground water nitrate removal in subsoil of forested and mowed riparian buffers zones. Journal of Environmental Quality. 28: 962-970.

Agren, G.I.; Bosatta, E. 1988. Nitrogen saturation of terrestrial ecosystems. Environmental Pollution. 54: 185-197.

Chesters, G.; Schiero, L. 1985. A primer on nonpoint source pollution. Journal of Soil and Water Conservation. 40(1): 9-13.

Cooke, J.G.; White, R.E. 1987. Spacial distribution of denitrifying activity in a stream draining an agricultural catchment. Fresh Water Biology. 18: 509-519.

Cooper, A.B. 1990. Nitrate depletion in the riparian zone and stream channel of a small headwater catchment. Hydrobiologia. 202: 13-26.

Correll, D.L. 1996. Buffer zones and water quality protection: general principals. In: Proceedings, International conference on buffer zones. Tresaith, Cardigan, UK: Samara Publishing Limited: 7-20.

Daniels, R.B.; Gilliam, J.W. 1996. Sediment and chemical load reduction by grass and riparian filters. Soil Science Society of America Journal. 60: 246-251.

Dillaha, T.A.; Reneau, R.B.; Mostaghimi, S.; Lee, D. 1989. Vegetative filter strips for agriculture nonpoint source pollution control. American Society of Agricultural Engineers. 32(2): 513-519.

Edwards, D.R.; Moore, P.A., Jr.; Daniel, T.C. 1996. Grassed filter strips can reduce losses of nitrogen and phosphorous in runoff. Better Crops. 80(4): 8-11.

Gilliam, J.W. 1994. Riparian wetlands and water quality. Journal of Environmental Quality. 23: 896-900.

Groffman, P.M.; Axelrod, E.A.; Lemunyon, J.L.; Sullivan, W.M. 1991. Denitrification in grass and forest vegetated filter strips. Journal of Environmental Quality. 20: 671-674.

Haycock, N.E.; Pinay, G. 1993. Groundwater nitrate dynamics in grass and poplar vegetated riparian buffer strips during winter. Journal of Environmental Quality. 22: 273-278.

Herron, N.F.; Hairsine, P.B. 1998. A scheme for evaluating the effectiveness of riparian zones in reducing overland flow to streams. Australian Journal of Soil Resources. 36: 683-698.

Hill, A.R. 1988. Factors affecting nitrate depletion in a rural stream. Hydrobiologia. 160: 111-122.

Hill, A.R.; Sanmugudas, K. 1985. Denitrification rates in relation to stream sediment characteristics. Water Resources Research. 12: 1579-1586.

Illinois Natural Resource Geospatial Data Clearinghouse. 2000. Department of Natural Resources Data-county [On-line]. Available: http://www.isgs.uiuc.edu/nsdihome/webdocs/county.html

Jacobs, T.C.; Gilliam, J.W. 1985. Riparian losses of nitrate from agricultural drainage waters. Journal of Environmental Quality. 14: 472-478.

James, B.R.; Bagley, B.B.; Gallagher, P.H. 1990. Riparian zone vegetation effects on nitrate concentrations in shallow groundwater. In: Mihursky, J.A.; Chaney, A., eds. New perspectives in the Chesapeake system: a research and management partnership. Publ. 137. Solomons, MD: Chesapeake Research Consortium: 605-612.

Jones, K.B.; Neale, A.C.; Nash, M.S.; Van Remortel, R.D.; Wickham, J.D.; Riitters, K.H.; O'Neill, R.V. 2001. Predicting nutrient and sediment loading from landscape metrics: a multiple watershed study from the United States Mid-Atlantic Region. Landscape Ecology. 16(4): 301-312.

Jordan, T.E.; Correll, D.L.; Weller, D.E. 1993. Nutrient interception by a riparian forest receiving inputs from adjacent cropland. Journal of Environmental Quality. 22: 467-473.

Lowrance, R.R.; Rodd, R.L.; Asmussen, L.E. 1983. Waterborne nutrient budgets for the riparian zone of an agricultural watershed. Agriculture Ecosystems and Environments. 10: 371-384.

Lowrance, R.R.; Todd, R.; Fail, J.; Hendrickson, O.; Leonard, R.; Asmussen, L. 1984. Riparian forests as nutrient filters in agricultural watersheds. BioScience. 34(6): 374-377.

Lyons, J.B.; Gorres, J.H.; Amac, J.A. 1998. Spatial and temporal variability of phosphorus retention in riparian soils. Journal of Environmental Quality. 27: 895-903.

Muscutt, A.D.; Harris, G.L.; Bailey, S.W.; Davies, D.B. 1993. Buffer zones to improve water quality: a review of their potential use in UK agriculture. Agriculture, Ecosystems and Environment. 45: 59-77.

Osborne, L.L.; Kovacic, D.A. 1993. Riparian vegetated buffer strips in water-quality restoration and stream management. Freshwater Biology. 29: 243-258.

Peterjohn, W.T.; Correll, D.L. 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. Ecology. 65: 1466-1475.

Pinay, G.; Decamps, H. 1988. The role of riparian woods in regulating nitrogen fluxes between the alluvial aquifer and surface water: a conceptual model. Regulated Rivers. 2: 507-516.

Schipper, L.A.; Cooper, A.B.; Dyck, W.J. 1991. Mitigating nonpoint source nitrate pollution by riparian zone denitrification. In: Borgardi, I.; Kulzelka, R.K., eds. Nitrate contamination: exposure, consequences and control. NATO ASI Ser. G. New York, NY: Springer-Verlag: 401-413.

Synder, N.J.; Mostaghimi, S.; Berry, D.F.; Reneau, R.B.; Hong, S.; McClellan, P.W.; Smith, E.P. 1998. Impact of riparian forest buffers on agricultural nonpoint source pollution. Journal of the American Water Resources Association. 34(2): 385-395.

United States Environmental Protection Agency. 1994. The quality of our nation's water: 1992. EPA 841-s-94-002. Washington, DC: United States Protection Agency, Office of Water. [On-line] Available: http://www.epa.gov/305b/execsum94.html

Van Miegroet, H.; Cole, D.W.; Foster, N.W. 1992. Nitrogen distribution and cycling. In: Johnson, D.W.; Lindberg, S.E., eds. Atmospheric Deposition and Forest Nutrient Cycling. Ecol. Stud. 91. New York, NY: Springer-Verlag: 178-196.